

Nonsteady behaviour of solar dynamic power systems with Stirling cycle for space stations

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Abstract

In the first part of this paper, a solar dynamic power system with a Stirling engine for space station application is described. Its unsteady behaviour is theoretically modelled and numerically simulated for four representative orbit configurations. The results are compared to that of a solar dynamic power module with a Brayton gas turbine.

In the second part, it is shown that the complex nonsteady behaviour of solar dynamic power modules with either the Brayton cycle or Stirling cycle can be analysed in a simplified way with sufficient accuracy for practical purposes on the basis of parametrizations and simple energy balances. © Elsevier, Paris

space station / space electrical power system / solar dynamic / closed Brayton cycle / Stirling cycle / unsteady behaviour

Zusammenfassung

Instationäres Verhalten solardynamischer Stromversorgungssysteme mit Stirling Kreislauf für Raumstationen. Im ersten Teil dieses Berichts wird ein solardynamisches Stromversorgungssystem mit Stirlingmaschine für Anwendungen in Raumstationen beschrieben. Das instationäre Verhalten wird theoretisch modelliert und für vier repräsentative Bahnkonfigurationen numerisch simuliert. Die Ergebnisse werden mit denen eines solardynamischen Stromversorgungsmoduls mit Bravton Gasturbine verglichen.

Im zweiten Teil wird gezeigt, daß das komplexe instationäre Verhalten von solardynamischen Stromversorgungsmodulen mit Brayton oder Stirling Kreislauf in vereinfachter Weise auf der Basis von Parameterisierung und einfachen Energiebilanzen mit ausreichender Genauigkeit für praktische Zwecke analysiert werden kann. © Elsevier, Paris

Raumstation / Stromversorgungssystem für die Raumfahrt / solar dynamisch / geschlossener Brayton Kreislauf / Stirling Kreislauf / instationäres Verhalten

Notations

Notations		cp_s	specific heat at constant pressure [J/kg K]
		Exp	experience factor
b_{ht}	effective width of the heat transfer fluid/ radiator [m]	f_{cold}	correction factor
$coef_i$	coefficient for the maximum cycle temperature	F_{rq}	Frequency [Hz]

* Correspondence and reprints.

k	$= \frac{\dot{m} c p_s}{2 \alpha b_{ht}}$
K_f	correction factor
L_{Rad}	radiator length [m]
$\dot{m}$	mass flow rate [kg/s]
p	exponent for the radiator temperatures
P_{mean}	cycle pressure [bar]
$P_{v, power}$	power output [W]
q_{spe}	specific heat [J/kg]
$\dot{Q}_{out}$	rejected power [W]
t_{sc}	time since the eclipse beginning [s]
T	temperature [K]
T_{max}	maximum cycle temperature [K]
T_{min}	minimum cycle temperature [K]
T_s	working fluid temperature in the radiator heat exchanger [K]
T_R	radiator temperature [K]
T_{wh}	heater wall temperature [K]
T_{wk}	cooler wall temperature [K]
V_0	swept volume [cm ³]
x	length coordinate [m]
α	heat transfer coefficient [W/m ² K]
Δ_{ecl}	duration of eclipse period [s]
Δ_{sun}	duration of sun period [s]
ΔT	temperature difference [K]
ε	relative pressure losses
η	efficiency, effectiveness
κ	isentropic gas index
π	compression ratio
ϑ	temperature ratio
ξ	pressure loss factor

Subscripts

c	cold side
comp	compressor
ecl	eclipse period
eff	effective
h	hot side
ht	heat exchanger
in	inlet
out	outlet
rad	radiator
rec	receiver
sun	sun period
th	thermal
tu	turbine

1. Introduction

Solar dynamic (SD) power system concepts have been considered, for many years, as an alternative to the usual

photovoltaic concepts for space station application [3], [9], [10].

They consist of a sun pointing collector which concentrates the solar radiation on a cavity receiver. A part of this energy will be stored as latent heat inside the receiver for use in the eclipse time and the rest will be transported to a thermal power process, which produces electricity. A heat pipe radiator is considered as heat rejection system. Because of their higher overall efficiency solar dynamic systems need smaller collector areas (factor 2 to 3) than photovoltaic power systems. Radiator and collector areas are to be positioned in order to optimize drag and heat rejection or collection, and so need less propellant for orbit keeping.

The two most interesting options for thermal power processes are the closed Brayton cycle (CBC) and the Stirling cycle.

Since the solar dynamic power systems are more complex than the photovoltaic ones, the analysis of their unsteady behaviour is necessary, before a decision concerning the future of these more efficient power systems for space stations will be taken.

A detailed analysis of an SD module with CBC was already carried out at DLR [6].

The purpose of this paper is the theoretical modelling, numerical simulation and comparison of the nonsteady behaviour of an SD module with Stirling cycle for four representative orbit configurations with that of the Brayton cycle SD module.

In a second part, a simplified model of SD power modules with Stirling or Brayton cycle will be presented for a simulation program, which is being developed for space station design at the Institute for Space Systems (IRS) of the Stuttgart University.

2. Modelling and simulation of the unsteady thermodynamic behaviour of SD power system modules with Stirling engine

2.1. Description of the whole SD system

Like the SD power module with Brayton cycle, the Stirling module consists of a heat pipe radiator and a heat pipe receiver with integrated latent heat storage. The total radiator area is divided into four equal plates. For each plate, the working fluid flows through the heat exchanger, where the heat will be transferred to the heat pipes.

The receiver (*figure 1*) has 37 identical heat pipes, parallel to the longitudinal axis, with integrated thermal energy storage rings (*figure 2*). As a latent heat storage medium, the phase-change salt LiF was used.

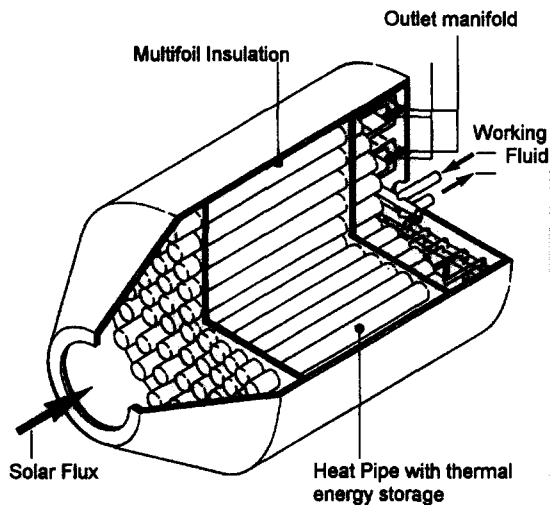


Figure 1. Heat pipe receiver.

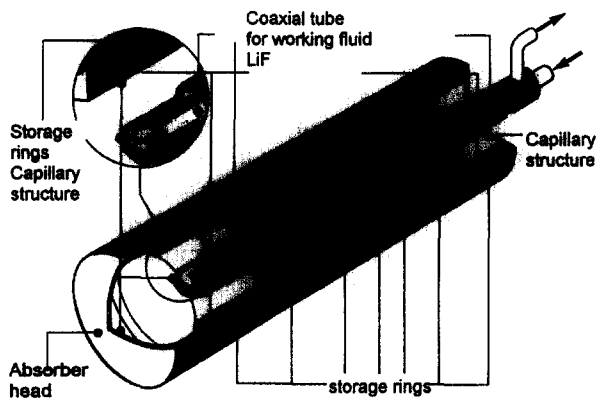


Figure 2. Receiver heat pipe with integrated thermal energy storage rings.

These components were adapted to the requirements of the Stirling engine. Figure 3 and figure 4 reveal why the interfaces with the receiver and the radiator for the Stirling module are different for the gas turbine. For the Brayton cycle, a helium-xenon gas mixture flows through the different components (receiver, gas turbine, radiator) and so transfers the heat to be furnished or rejected. There is only one circuit for the working gas.

On the other hand, the Stirling engine itself represents a closed unit. The process heat will be transferred to the working gas through two contact areas (heater and cooler). Two interfaces must be specified:

- The interface between Stirling cooler and radiator is designed as a pumped loop circuit with a synthetic working fluid (Dowtherm J);

- The interface between the Stirling heater and the receiver is designed as a heat pipe interface, which is penetrated by the receiver heat pipes. In this way the heat will be directly transferred from the vapour cavity of the receiver heat pipes to the vapour cavity of the interface.

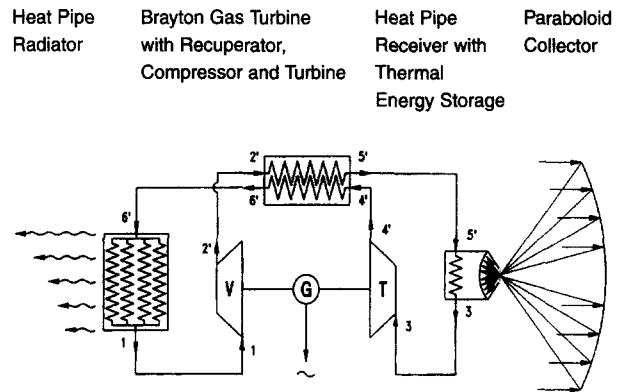


Figure 3. Solar dynamic power module with the Brayton cycle.

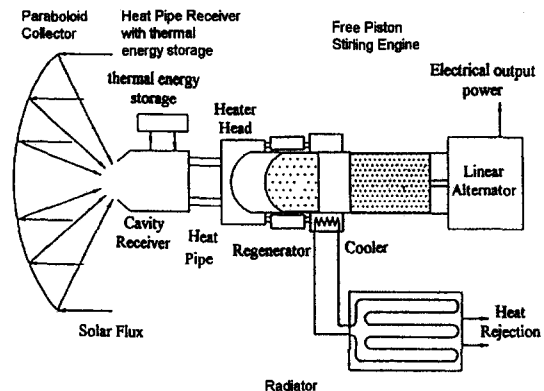


Figure 4. Solar dynamic power module with the Stirling cycle.

This one ends in a cylindrical heat pipe plate around the engine. The heater tubes of the Stirling engine will be included in heater fins, which serve as condensation zone of the receiver interface.

Besides, the receiver heat pipes are simpler than for the Brayton cycle: the inner tube for heating the helium-xenon gas mixture is not necessary in this case.

2.2. Choice and thermodynamic modelling of the Stirling engine, radiator and receiver

For space application, a Free Piston Stirling Engine (FPSE) with helium as the working gas was chosen as a promising candidate for its high reliability and its extremely long life. The FPSE uses the resonant dynamics between the displacer piston and the subsystem working piston-linear generator to control the thermodynamic process and can therefore be hermetically sealed.

The chosen FPSE is the 25 kWe Component Technology Power Converter (CTPC), figure 5. It was designed and fabricated by Mechanical Technology Inc. (MTI) for NASA and consists of two opposed 12.5 kWe FPSE, which share a common expansion space and so build a free oscillator. Thus the engine is balanced and in

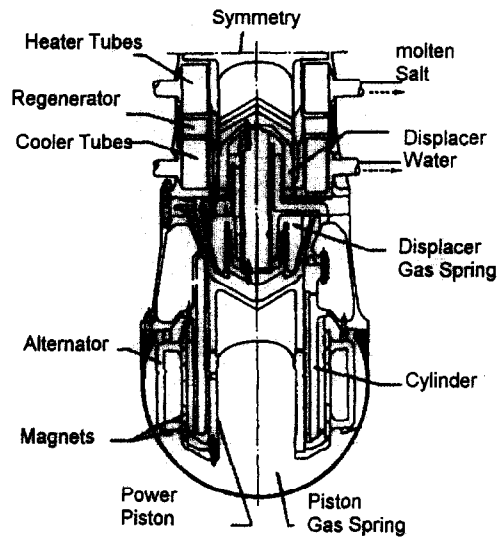


Figure 5. Component technology power converter (CTPC).

this way does not transmit undesired oscillations to the space station.

For a mean pressure of 150 bar, a frequency of 70 Hz, a heater wall temperature T_{wh} of 1050 K and a cooler wall temperature T_{wk} of 525 K, it has an efficiency of 22 %.

In order to compare the two complete systems, Brayton and Stirling, the initial CTPC Stirling engine had to be re-dimensioned, that is scaled and optimized with the help of a developed simulation program. A heater wall temperature of 1093 K and a cooler wall temperature of 313 K were assumed. The efficiency of the resulting Stirling engine is 45.4 %.

Operating conditions for the Brayton gas turbine:

Hot temperature T_h	= 1093.15 K
Cold temperature T_k	= 243.15 K
Efficiency	= 44 %
Electrical output power	= 25 kW _e

Operating conditions for the scaled and optimized CTPC-Engine:

Mean pressure	= 150 bar
Frequency	= 70 Hz
Heater wall temperature T_{wh}	= 1050 K
Cooler wall temperature T_{wk}	= 525 K
Efficiency	= 45.4 %
Electrical output power	= 2 x 12.5 kW _e

The developed program delivers detailed information on the internal phenomena of the engine and thus also on the influence of the engine on the whole SD system. It enables the separate estimate of the real effects of the heat exchangers and of the regenerator on the engine.

For the simulation of the unsteady behaviour of the Stirling engine over an orbit, it was assumed that the interaction between thermodynamics and dynamics inside the engine, by limited variations of the heater and cooler wall temperatures, remains small enough and that the engine inside these temperature limits operates in a stable way. Therefore the additional volume variations, caused by the influence of the dynamics, can be neglected and the piston motions can hence still accept a general modeling in form of sinusoidal volume variations.

The heat pipe radiator and the heat pipe receiver with integrated latent heat storage elements and their interface were modelled with a finite elements method. Heat transport relations for all control spaces to be considered were set up for these two components. The established energy balances results in a nonlinear differential equations system, of which solution gives the different temperatures inside the considered components.

2.3. Simulation of the coupled SD power system

The three key components of the SD module with Stirling engine (receiver, Stirling engine and radiator) were then coupled together and the total SD module was simulated for the same reference orbit constellations and tracking concepts of the collector and of the radiator as that for the SD module with Brayton gas turbine.

Two different orbit altitudes were chosen, with maximum and minimum eclipse durations for each ($i = 28.5^\circ$, $e = 0$, Start: 21.06.2000):

	Maximum orbit altitude a = 500 km Orbit period 94.4 min		Minimum orbit altitude a = 250 km Orbit period 89.1 min	
Ω_s	180°	36.8°	180°	37.5°
Eclipse Duration	27.6 min (mini)	35.4 min (maxi)	31.6 min (mini)	36.8 min (maxi)

To design the solar dynamic components, the case with maximum eclipse duration and maximum orbit altitude was chosen according to [6]. Thanks to an appropriate regulation by variation of the working medium mass flow rate in the cooling circuit, this power system can then be adapted to the different thermodynamic boundary conditions of the other station orbits.

In the SD system with Brayton cycle, pressure and mass flow rate of the working gas in the whole circuit are coupled together through the SD components, while the pressure inside the FPSE is not directly coupled to this mass flow rate. However the pressure could be a strong regulation parameter, because the Stirling engine power is directly proportional to the mean pressure level.

With the help of the numerical simulation for the case of the reference orbit, it results that 94.80 kW – in comparison with 99.15 kW for the SD module with Brayton gas turbine – must be constantly radiated in the receiver aperture during the sun period. The necessary collector area is therefore correspondingly smaller, which is favorable to the total mass of the SD module, but also to the drag in LEO atmosphere and to the propellant consumption.

Figure 6 compares the variation of the extreme temperatures of the Brayton and Stirling cycle for the four reference orbits.

The minimum cycle temperature is mainly determined by the unsteady behaviour of the albedo and Earth infrared radiations for the different orbits. In the Stirling cycle, the maximum cooler wall temperatures over an orbit are very close to each other; on the contrary, the dispersion of the heater wall temperature is more important than in the Brayton cycle.

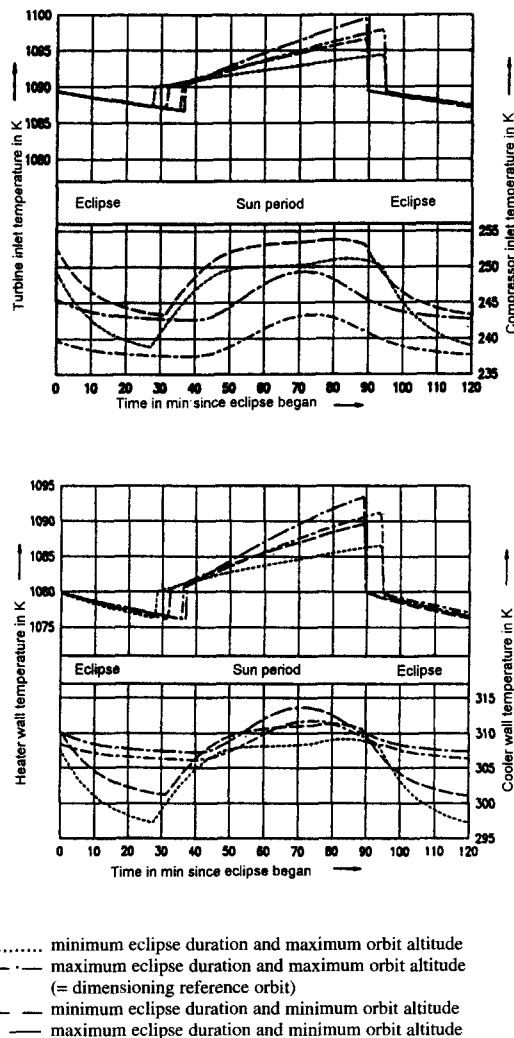


Figure 6. Variation of the extreme temperatures of the Brayton (above) and Stirling (below) cycle for the four reference orbits.

On the one hand, a fluid is used as working medium in the cooling circuit of the Stirling cycle instead of a gas as in the Brayton cycle; on the other hand, the thermal inertia of the radiator contributes also to compensate the differences in the temperature variations on the cold side between the Brayton and the Stirling module.

On the hot side, the temperature level is roughly the same as for the Brayton cycle because of the thermal absorbing latent heat storage medium. We recognize here the unload characteristic of the latent heat storage in the receiver during the eclipse and the load process during the sun period.

The different slopes of the maximum cycle temperature result from the different mass flow rates corresponding to the chosen regulation strategy for the cycle.

The thermal resistance inside the heat pipes plays also a role in this temperature variation. Indeed, it increases proportionally to the distance of the phase-change area from the heat pipe axis.

The receiver heat pipes of the Stirling module have smaller dimensions. For example, their outer radius is 8 mm smaller than that of the Brayton module. This is, indeed, favorable to a smaller volume and a corresponding lower mass of the total receiver, but the thermal resistance will be less compensated by the area at the phase-change area.

The Stirling engine itself plays a thermal absorbing role, not only at the heater wall thanks to the regenerator inside the engine, but also in the heat exchanger around the engine thanks to the specific heat of the working fluid.

Nevertheless, we can state that the form of the graphs between the Stirling and the Brayton modules is preserved. That means that the engine type (gas turbine or piston machine) is not determining the operating characteristics of the total SD system.

Figure 7 represents the variations of the wall temperature in the regenerator walls. We can see that these

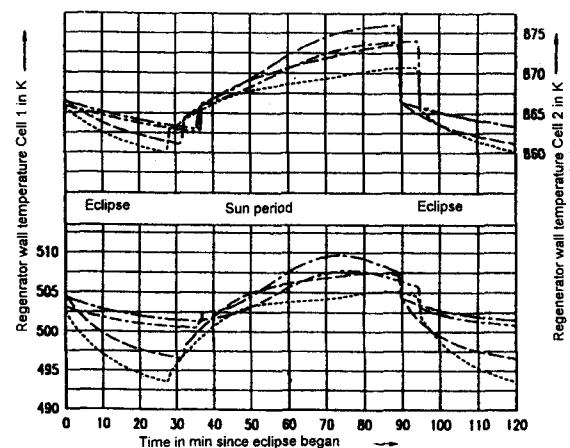


Figure 7. Variation of the wall temperature in the regenerator cells (see figure 6 for legend).

temperatures are determined by both the variation of the hot and cold temperatures.

Radiator temperature gradients	Stirling	Brayton
in longitudinal direction of the radiator	$\Delta T \approx 18 \text{ K}$	$\Delta T \approx 90 \text{ K}$
in longitudinal direction of the heat pipes	$1.8 \text{ K} < \Delta T < 2.5 \text{ K}$	$2 \text{ K} < \Delta T < 10 \text{ K}$

Instead of a power reducing pumped loop system with radiator heat exchanger, a heat pipe interface between the Stirling cooler and the radiator structure will be more judicious for a favorable isothermal heat rejection. This would moreover reduce the total mass of the SD module.

For the SD module with Stirling engine, the same radiator dimensions as for the Brayton system were chosen. Since the efficiency of the Stirling cycle is better than that of the Brayton cycle, the radiator has to reject less heat (about 6.5–7 kW less). The radiator area could hence be smaller dimensioned, which would minimize the total mass of the SD module. This represents again an advantage for the transport and operation costs.

In figure 8 the unsteady behaviour of the electrical output power with regard to the two thermal cycles may be compared for the four representative orbits. The results show that the reference output power of 25 kW for the system dimensioning was reached for the two systems. The electrical output power oscillates due to the changing of the orbital boundary conditions only of $\pm 1.95\%$ in comparison with $\pm 2.5\%$ in the Brayton case. This shows again the adapted combination of the radiator tracking concept (that is the radiator optimizes at the

same time the drag and the accumulated radiations), of the dimensioning criterions of the SD components and also of the thermal absorbing behaviour of the Stirling engine.

The advantages of the SD module with the Free Piston Stirling Engine cycle in comparison with that of the Brayton cycle can be summarized as follows:

- the Stirling engine is hermetically sealed,
- the receiver heat pipes are simpler and smaller,
- the collector and radiator areas are smaller,
- the total SD module is more compact with lower total mass,
- the fluid loop circuits are uncoupled, which leads to a better system control : control by the mass flow rate and mean pressure is possible,
- the oscillations of the output power are smaller,
- as in the case of Brayton cycle, no oscillation impact on the space vehicle.

3. Simplified model and simulation for the IRIS Program

3.1. Description of the model

In the field "space technology and utilization" of the Institute for Space Systems (IRS, Stuttgart University) a working environment for the design of space stations and platforms is being at present constructed as part of the Space Station Design Workshop.

With the help of this development, the designer will be in a position to define in a few days a space station concept, to simulate and analyze the essential features and sub-systems of the mission and to estimate and optimize the concepts.

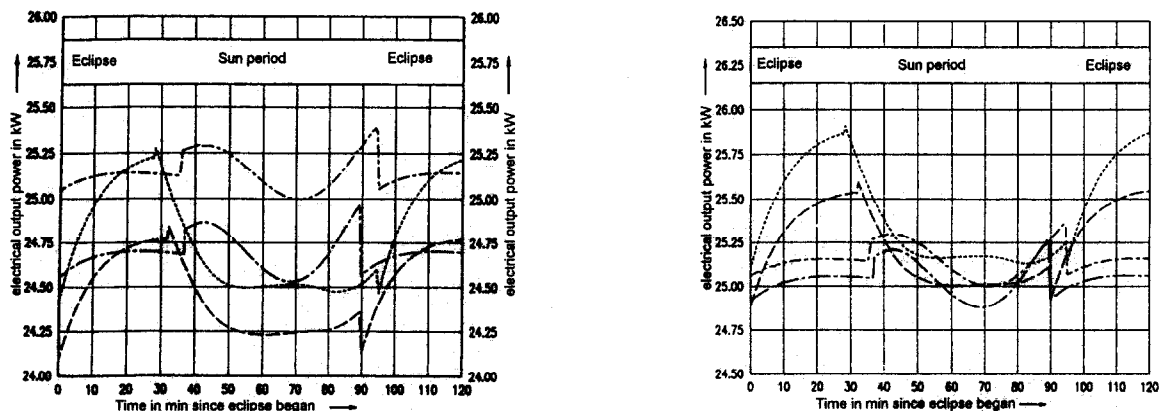


Figure 8. Unsteady behaviour of the electrical output power for the four representative orbits respectively for the two thermal cycles, Brayton cycle on the left and Stirling cycle on the right (see figure 6 for legend).

IRIS, as a simulation program for the position and motion of a space system on orbit, is an essential part of this development.

As a potential future power system concept, the solar dynamic power systems can also be simulated. The aim of the second part of this work is the creation of a simplified model with sufficient accuracy for the simulation of the unsteady behaviour of these systems. Both the Brayton gas turbine and the Stirling engine can be simulated as thermal processes.

The approach consists of using simplified equations and, if necessary, of off-line designing calculations with the detailed master program.

IRIS expects from the user only a few parameters, which characterize the solar dynamic components and correspond to the following different simplified models:

- The whole Brayton cycle can be calculated by simple relations which are functions of the variable turbine and compressor inlet temperatures:

The specific heat to be supplied by the receiver and that to be rejected by the radiator can be expressed as follows:

$$q_{spe} = a T_{tu, in} + b T_{comp, in} \quad (1)$$

where

$$a = f(\eta_{ht}, \xi, \pi, \kappa, \eta_{tu})$$

$$b = f(\eta_{ht}, \xi, \pi, \kappa, \eta_{comp}) \quad (2)$$

with the pressure loss factor:

$$\xi = \frac{1 + \varepsilon_{rad} + \varepsilon_{ht, h}}{1 - \varepsilon_{rec} - \varepsilon_{ht, c}} \quad (3)$$

The effective efficiency of the Brayton cycle with regeneration and with consideration of pressure losses is:

$$\eta_{eff} = \left[\frac{a T_{tu, in} + b T_{comp, in}}{c T_{tu, in} + d T_{comp, in}} \right] \quad (4)$$

where

$$a = f(\xi, \pi, \kappa, \eta_{tu})$$

$$b = f(\pi, \kappa, \eta_{comp})$$

$$c = f(\eta_{ht}, \xi, \pi, \kappa, \eta_{tu}) \quad (5)$$

$$d = f(\eta_{ht}, \pi, \kappa, \eta_{comp}).$$

- The principle of the simplified radiator model consists in the approximation of the working medium flow temperature in the radiator heat exchanger with an exponential function, in which the exponent p is dependent on the solar radiation and heat rejection conditions of the working medium and its mass flow rate. Assuming that the radiator temperature gradient in the heat pipe longitudinal direction is negligible, the radiator temperature can be calculated for each time step with a one dimensional function.

Flow temperature at x :

$$T_s(x) = \Delta T \left(1 - \frac{x}{L_{rad}} \right)^p + T_{s, out} \quad (6)$$

where

$$\Delta T = T_{s, in} - T_{s, out} \quad (7)$$

Radiator temperature in the middle of the area strips at x :

$$T_R(x) = \Delta T \left(1 - \frac{x}{L_{rad}} \right)^{p-1} \left[1 - \frac{x + k p}{L_{rad}} \right] + T_{s, out} \quad (8)$$

where

$$k = \frac{\dot{m} c p_s}{2 \alpha b_{ht}} \quad (9)$$

- The simplified receiver model is characterized by the fact that the outlet temperature of the working gas for the Brayton cycle or the heater wall temperature for the Stirling cycle can be approximated by simple linear functions during the eclipse and sun periods. These are a function of the orbit altitude, the duration of the eclipse and sun periods, and of the working fluid mass flow rate.

During the eclipse period:

$$T_{ecl} = coef_{1, ecl} + \frac{coef_{2, ecl}}{\Delta_{ecl}} t_{sc} \quad (10)$$

During the sun period:

$$T_{sun} = coef_{1, sun} + \frac{coef_{2, sun}}{\Delta_{sun}} (t_{sc} - \Delta_{ecl}) \quad (11)$$

where $coef_{1, sun} = f(\text{orbit altitude, duration of the sun and eclipse period, working fluid, mass flow})$.

- The simplified key relations for the simplified model of the Stirling engine are that of the engine power output, the thermal efficiency and the rejected heat, which respectively contain a factor, which is a function of the temperature ratio $\vartheta = T_{max}/T_{min}$, the mass flow rate and the mean pressure:

Power output for real machines with losses:

$$P_{v, power} = 2 Exp P_{mean} Fr_q V_0 \frac{T_{max} - T_{min}}{T_{max} + T_{min}} \quad (12)$$

Thermal efficiency :

$$\eta_{th} = Kf \frac{T_{max} - T_{min}}{T_{max}} \quad (13)$$

Power to be rejected from the Stirling cycle:

$$\dot{Q}_{out} = P_{v, power} \left(1 - \frac{1}{\eta_{th}} \right) f_{cold} \quad (14)$$

Graphical presentations of the experience factor Exp , the correction factors Kf and f_{cold} (all functions of $\vartheta, \dot{m}, P_{mean}$) can be found in [1].

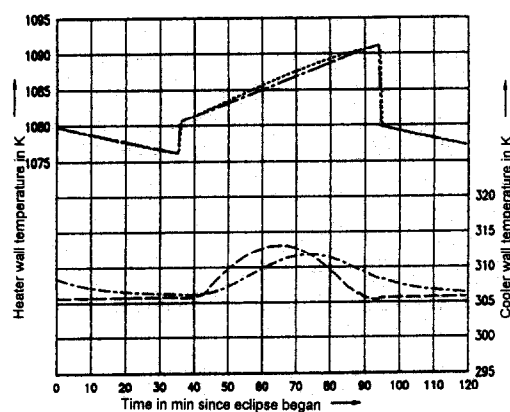
The other characteristic thermodynamic variables of the total SD module can be calculated with the help of energy balances and iteration processes.

3.2. Results

The four chosen reference orbits were simulated with the whole simplified model for the solar dynamic power systems. The obtained results were compared with that of the detailed modelling.

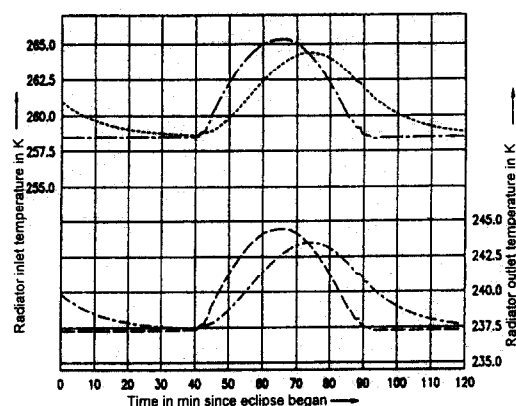
Because the simulation results obtained with IRIS for the Brayton cycle and for the four reference orbits correspond very well to that of the complex simulation program with a maximum error of 1%; they are not shown here. These results confirm hence the simplified model for the receiver outlet temperature.

In *figure 9* the heater and cooler wall temperatures of the Stirling engine calculated with IRIS and with the complex simulation are shown for the reference orbit. The heater wall temperature calculated with the simplified theory corresponds very well to that from the complex simulation. On the other hand, there are differences in the behaviour of the cooler wall temperature. This is not only due to the iterative character of the radiator model but also to the iteration for the simulation of the heat exchanger around the Stirling cooler. This shows also *figure 10* for the radiator inlet and outlet temperatures, what leads to a maximum error of 1.3 % for the electrical output power on a half of the FPSE. Given the



Heater wall temperature
 with the detailed modelling
 ——— with IRIS
 Cooler wall temperature
 with the detailed modelling
 ——— with IRIS

Figure 9. Extreme temperatures of the Stirling cycle for the reference orbit calculated with IRIS and with the complex simulation.



Radiator inlet temperature
 with the detailed modelling
 ——— with IRIS
 Radiator outlet temperature
 with the detailed modelling
 ——— with IRIS

Figure 10. Radiator inlet and outlet temperatures of the Stirling engine for the reference orbit calculated with IRIS and with the complex simulation.

quite good results for the heater wall temperature, we obtain, with the energy balance of the heat storage in the simplified receiver model that the energy budget of the system is as expected balanced.

Figure 11 represents the extreme temperatures of the Stirling cycle for the reference orbit "minimum eclipse duration, maximum orbit altitude". The cooler wall temperature calculated with IRIS moves away from that of the complex simulation because of the iterative calculation processes of the model of the Stirling engine and that of the radiator. But the temperatures on the cold side differ from that of the complex simulation by a maximum of only 5 %.

Finally, we can conclude that the developed simplified model for the SD module with Brayton cycle gives very good results, but for the Stirling cycle inevitable inaccuracies appear due to the iteration process between the simplified model for the Stirling engine and that of the radiator. For the four simulated reference orbits, the maximum error, however, is less than 5 %.

4. Summary

The advantages of the utilization of a free piston Stirling engine were shown in comparison with a Brayton gas turbine. With the help of the developed detailed modelling and simulation, the complex non-steady behaviour of solar dynamic systems with the

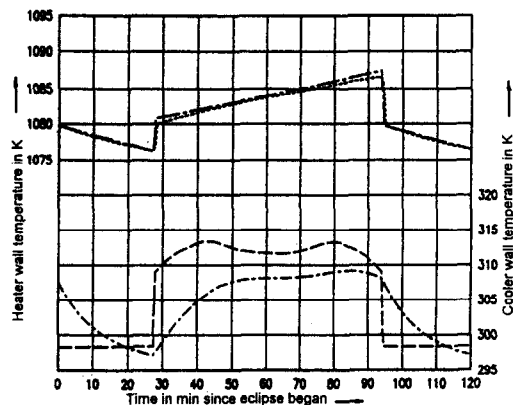


Figure 11. Extreme temperatures of the Stirling cycle for the reference orbit "minimum eclipse duration, maximum orbit altitude" calculated with IRIS and with the complex simulation (see figure 9 for legend).

Stirling engine could be for the first time completely analyzed. On that basis, the essential starting points for improvements under consideration could be determined.

The whole cycle could, for example, be controlled in the future by the pressure variation inside the Stirling engine. For this, the modelling of the interaction between the thermodynamics and the dynamics inside the Stirling engine is necessary, because the free piston Stirling engines use the resonant dynamics between the displacer piston and the working piston to control the cycle. This interaction can under certain conditions strongly influence the behaviour of the whole system and is essential for the stability of the Stirling cycle and its good performance. This should be an important future research activity.

A possibility for such a simulation consists for example in the linear harmonic analysis of Chen and Griffin [2]. But such a program is restricted to a specific engine geometry and hence lost its general character. It will also have longer calculating times and a parallel running test campaign.

As said before, only free piston Stirling engines are suited for space application due to their low vibration, no rubbing surfaces, etc. Since they are still under development, there is lack of data on reliability and life duration.

For real missions, the needed long life of such Stirling engines must still be demonstrated. Specific loss mechanisms inside the free piston Stirling engines must also be removed during their development, because they have a significant influence.

Experiences with respect to life time exist so far only for the gas turbine (CBC). Even a very small turbine (2 kW) could demonstrate its technical maturity with

more than 500 hours of operation (about 300 simulated orbits) under space conditions in the Ground Test Demonstrator of NASA-Lewis [8].

For current technologies [7] solardynamic and photovoltaic power systems have about the same launch masses. The power/weight ratio is about 7–10 W/kg for these two types of power systems. [5] shows for future SD technologies a mass advantage compared with photovoltaic systems. This mass saving, however, is different for the various missions (depending very much on their properties and requirements).

There already exists an advantage for Solar Dynamic Power Systems (SDPS) for missions like the International Space Station due to the reduced requirements: small collector area and no batteries. Both result in a smaller number of supply flights for fuel replacement for orbit correction and for the exchange of batteries. This again results in reduced life cycle costs of SDPS missions. These arguments are generally valid for missions in the low earth orbit. A comparison between photovoltaic power systems and an SDPS clearly reveals the latter to be most promising for reducing life cycle costs of large space stations considerably [4].

Further developments of SDPS components will lead to mass reductions of the receiver (ESA project HEPTES presently carried out by DLR), of the concentrator (fibre composite construction, inflatable mirrors) and of the radiator. Beyond that SDR will be an interesting alternative for space power supply of more than 30 kW.

In the second part of this paper, it was shown that it is possible to represent the nonsteady behaviour of solar dynamic systems, for both the Brayton cycle and the Stirling cycle, by a simplified model with the help of parametrizations and energy balances with for design purposes sufficient accuracy and relatively short calculating times, in order to analyze, for example, the influence of these systems on the position and motion of a space station.

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